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ABSTRACT

A principal limitation of frame-based computer assisted instruction (CAI) results not from the characteristics of the computer medium, but rather from prior instructional design practices, specifically the logical abstraction of behavioral objectives. Learning hierarchy-based instruction implemented in the interactive computer-based medium results in sets of both global and local branching difficulties. Such difficulties include the potential for the subtree mastery assumption to be falsified or for the occurrence of response errors which could stem from psychological or cognitive considerations rather than from logical ones. Although large-scale translation of extant curricula based on logical hierarchies into the CAI format offers no fundamental advance in the practice of instruction, the interactive quality of the new medium does promote change toward a reformulation of instruction in terms of the more appropriate alternative of psychological task analysis. Eight references are listed. (Author/LMM)

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THE LIMITS OF FRAME-BASED CAI

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ABSTRACT

A theoretical analysis of the limits of frame-based CAI is presented. A principal limitation of this form of instruction results not from the character of the computer medium, but rather is inherited from prior instructional design practices; specifically, logical abstraction of behavioral objectives. Learning hierarchy based instruction implemented in the interactive computer-based medium result in sets of both global and local branching difficulties which are described.

The concept of psychological task analysis is developed and suggested as an appropriate alternative to logical analysis. Large-scale translation of extant curricula (based on logical hierarchies) into the CBE format, it is argued, offers no fundamental advance in the practice of instruction. However, the interactive quality of the new medium promotes change toward a reformulation of instruction in terms of psychological analyses.

THE LIMITS OF FRAME-BASED CAI

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Introduction

As commonly used, the modifier "frame" in frame-based CAI refers to the recognizable format of programmed instruction, namely a horizontal band on a page in a workbook. For CAI, however, a frame is more like one cell in a motion picture: instead of moving a cover sheet down the page of a programmed instruction workbook, the student is shown a temporally ordered sequence of frames, each more or less a separate display.

It has been pointed out that a better conceptualization of programmed instruction, or of frame-based CAI, has to do with the processes of lesson development, rather than the appearance of the resultant product (Bunderson and Faust, 1976). These processes are (1) the development of instructional objectives, (2) preparation of learning sequences which effectively and efficiently bring about mastery of those objectives, and (3) a validation process in which student performance is compared against the instructional objectives. If there is a mismatch between desired and obtained learning outcomes, corrective action is the responsibility of the designer, not the learner. The resultant product, then, can be described as validated, objective-based instruction. The objective is the conceptual frame of frame-based CAI.

The behavioral objective is traditionally viewed from two different perspectives in the culture of computer-based instructional

systems. On the one hand, the objective is a convenient chunk of information on which to base instruction, e.g. "the objective of this lesson is..." On the other hand, it is a convenient building block, or atom, to form the basis of a complex assemblage of information, e.g. "the objectives covered in this course are..." One can recognize the first perspective as the necessary viewpoint of frame-based CAI and the second as the vantage of CMI, computer managed instruction. The centrality of objectives is apparent: this concept stands squarely on the line of demarcation between CAI and CMI.

We bring in CMI at this juncture not to widen our topic, but of necessity. The line between CAI and CMI is not easily drawn. In particular, it moves toward one or the other in concert with a choice of the "graininess" of objectives. As objectives become coarser, they define more content to be encapsulated by the CAI lesson. At the same time, there are fewer such "lessons" to stack into the management structure of CMI. Conversely, as objectives become finer, they define less content. The CAI lessons are smaller and there are more of them to be managed by CMI.

It should come as no surprise that an argument concerning the limits of frame-based CAI turns to a consideration of the limitations of any instruction based on the behavioral objective. This paper will now take just such a turn. However, the interactive quality of frame-based CAI is a feature quite distinct from its basis on objectives. The interactivity is manifest in two ways, feedback and branching. Therefore, the second section of this paper examines these interactions between student and program. Finally, it is

inevitable that the objectives-based and interactive qualities of frame-based CAI interact with each other. Any full treatment of the limits of frame-based CAI must examine these patterns, as this paper does in its final section.

The Abstraction of Objectives

We are probably all familiar with instructional or behavioral objectives. Briefly, these are statements of what is to be taught, at what level, of mental complexity, and of how learning is to be measured in behavioral terms. Behavioral objectives provide a basis for the distinction between norm referenced and criterion referenced testing. They offer the means to evaluate learning against an absolute metric of definable knowledge rather than against the relative metric of group performance. Instructional objectives are the cornerstone of individualization and of instructional technology.

A primary criticism of objectives per se has to do with the processes by which they are abstracted from what is to be learned. This process of abstraction is often based on a logical analysis of the curriculum content. Here, a finished edifice of knowledge, such as algebra, is successively refined resulting in a hierarchical structure termed a learning hierarchy (Gagne, 1977). The term hierarchy implies a subordinant/superordinate relationship between its elements. In the case of a learning hierarchy, the relationship is one of prerequisites.

We shall continually refer to the term logical analysis. Hence, we would like to clearly define this term. Logical analysis is based on a representation of knowledge which is a formal synopsis

of results. A body of knowledge as it is newly discovered is typically a loose collection of rules of thumb (heuristics) and weakly connected results. As new knowledge develops, its original active procedural quality is successively refined, axiomatized, and canonicalized into a structured body of knowledge. Logical analysis addresses this formal structure and decomposes it into logical components reflecting the deductive rigor which gives it its canonical form. The result reads like the table of contents of an algebra book or the scope and sequence of school mathematics curricula.

Such logical analyses make the erroneous assumption that a corpus of knowledge when so divided has a direct bearing on how it is learned. Gagne attempts to strengthen the bearing by basing the design of instruction for an objective on learning theory. But this intervention of learning theory comes along too late. The objective itself, in the process of abstraction, may already have lost any meaningfulness to the learning process.

A case can be made that psychological task analysis is a more suitable basis for instructional design (Brown, 1979; diSessa, 1977; Greeno, 1976; Resnick, 1976). The term psychological task analysis emphasizes that knowledge must be analyzed in vivo; that is, it cannot be analyzed separately from the vessel, the human mind, which created and contains it. Such analyses should capture the intellectual mechanism of creativity and discovery. A psychological task analysis is inherently concerned with the process of understanding and reasoning and not the results, the logical synopsis, of such understanding and reasoning.

For example, the logical reduction of subtraction to an algo-

rithmic sequence completely misses the provision to the student of any insight into the reasons why the algorithm has its particular form. Its meaningfulness, its psychological meaningfulness, is lost.

Psychologically relevant solutions to task analysis are not readily at hand. John Seely Brown (1979) has painstakingly developed such an analysis for subtraction. The issue is not simply that we have chosen to ignore psychological relevance in task analysis. It is more that the possibility, necessity and technology for such analyses are just now being explored. In the meantime, the bulk of extant curricula is formulated in terms of behavioral objectives and is logically structured. Any great florescence of computer-based instruction (and we feel such a florescence is soon forthcoming) will borrow on what has been done before, e.g. on established sets of behavioral objectives. In fact, a cursory glance at curricula developed by the Mitre Corporation for TICCIT or by Science Research Associates for their new CMI products confirms this point. Reformulations of curricula along psychologically relevant lines will occur, but at a slow pace. Hence, a critical examination of just how logical hierarchies of behavioral objectives are suited to the computer medium is called for.

The Interactivity of the Computer-based Medium

The interactivity of frame-based CAI is manifest as feedback and branching. These two terms are extremely frequent descriptors in the jargon of computer-based instruction. Feedback, as typically used, refers to a feedback message a learner receives in response to his or her answer to a question. Branching, again a common

concept, refers to the capability of a computer to accommodate the ensuing line of instruction to the nature of the learner's current responses or needs. A good example of a simple branch is the help sequence or hint.

Critical examination of these two features of interactivity indicates that feedback is a special case of branching. Feedback is a non-interactive branch, one in which the learner passively observes the feedback message and is looped back to the question again. This non-interactive quality is in strange contradiction with the active equilibrating or stabilizing quality which is a part of the term feedback as originally defined in cybernetic theory. It is worth while to reclaim this term from the jargon and ask, really, what is the role of feedback, in its proper usage, in frame-based CAI?

In cybernetic theory, feedback is both a noun and a verb. As a verb, feedback is the return of a portion of the output of a process or a system to its input, usually to keep the process or system operating within predetermined limits. As a noun, feedback is that portion of the output so returned. It is possible that the noun feedback actually is "of the process" being controlled, as in the motion of a steam governor. It is also possible that the noun feedback is an abstraction, an analog, or a symbolic representation of what is being controlled, as in the voltages in a thermostat standing for temperature.

Let us look at what is said to be feedback in CAI. What is the process involved? Well, that entirely depends on the task at hand, or our conception of the task at hand. Suppose the task is very simple, say foreign language vocabulary acquisition. We are shown

"luz" and are to respond "light." Then, the process is one of establishing this association. Feedback messages for correct and incorrect responses are incorporated in the responding organism and the stable response "luz--light" is eventually achieved.

But we very seldom have such simple tasks as instructional goals. More routinely we require a response which exhibits understanding. Now, in this case, feedback messages for correct and incorrect responses are only incorporated in the responding organism to the extent that they themselves are understood. If not, the responses engendered are without meaning. What assurance do we have in using feedback messages that they are providing adequate meaningful genuine feedback to the learner? None.

It is the responsibility of the lesson designer to verify that feedback messages really work as intended--as feedback. One common practice is to tailor the incorrect response message for each trial to the nature of the error underlying the response. Subsequent to a number of unsuccessful trial responses there are two possibilities. Either the user is shown the correct answer and passed along to the next frame in the logical progression of instruction, or the user is branched somewhere else. If the user is simply passed along, one could hardly call the process he or she has just been through feedback! The only viable alternative is to address the learning difficulty through branching. The role of branching is to serve as genuine feedback. It is an attempt to reduce the difference between desired and obtained learning outcomes.

This brings us to a consideration of the second manifestation of interactivity, branching. In an analysis of branching we come up

squarely against the real limitations of frame-based CAI, and these limitations have to do with the interaction of such branching with the a priori hierarchical structure of the objectives on which instruction is based.

Interdependency Between Hierarchical Structure and Interactivity

A specific model of the hierarchical structure of objectives-based instruction is now needed. We have pointed out two basic features of the model: that the subordinant/superordinate relation of a hierarchy in this case is one of prerequisites, and that the objective forms the line of demarcation between what is taught (CMI) and how it is taught (CAI). Given any node in the hierarchy, the sub-hierarchy of objectives below it constitutes an exhaustive list of what must be learned to master the target objective and how this is to be taught. Mathematically, this could be re-expressed as this four-tuple: Node = (objective, subtree, instruction, criterion testing). A terminal node in the tree, or a simple isolated lesson, would have no subtree and the node would simply consist of the traditional components of a lesson: an objective, instruction, and criterion test of mastery.

By definition of a validated learning hierarchy, if the subtree of a node is in the learned state, it is necessarily possible to master the current node. If progress through the tree is criterion referenced, presence at a node of instruction implies mastery of its subtree. Therefore, any difficulty encountered by a learner in the instructional sequence for this node must be remediable in the context of the current node alone. Branching need not leave the node,

that is, instructionally sufficient branching is contained within the instructional package of the node, the CAI lesson. There is no logical need for CAI branching to interact with the larger CMI hierarchy.

But will real-life instructional interactions always turn out so nicely? Branching difficulties can arise on either the global (CMI) or the local (CAI) level. Let us consider the global level first.

Global Difficulties: There are at least two things that can go awry at this level. First, the subtree mastery assumption could be falsified. Second, response error could stem from psychological (cognitive) considerations rather than from logical ones. Let us examine these two cases in turn.

The first case is non-mastery of the subtree. How could this occur? Basically, in three ways. The most straightforward way is simple forgetting. The learner forgets something he or she once demonstrated mastery of. The remedy in this case is to branch back to the forgotten node, if it can be found, for relearning. The learner then returns to the target node. Now with a mastered subtree, instruction proceeds smoothly.

A second cause of non-mastery is related to signal detection or statistical theory. Here, a node in the subtree awards mastery status to the learner when it was not warranted. In short, if the criterion tests for each node are not exactly accurate in assigning mastery, the resultant non-mastery of a subtree will eventually stop progress. In this case the remedy is not branching. Chances are that if we branch the student back to the offending node, he or she will slip

through the same loopholes and the problem will remain. In this case, the only assured remedy is to redesign the criterion testing and/or instruction in the offending nodes. Of course, this does not meet the immediate needs of the student.

A third cause of subtree non-mastery is even more systemic. Here, the subtree might have structural omissions of valid prerequisites. This would be due to an error in the validation procedures. Its remedy is revalidating the hierarchy, isolating and adding the missing nodes. Naturally, this also includes writing the criterion tests and instruction for the newly discovered node. This cannot help the unfortunate student who discovered the bug in the hierarchy, but perhaps this student can be instructed "by hand" and counselled regarding his or her great contribution to later students.

Our second case of things going awry at the global level is psychological. As we have pointed out above, as basic limitation of frame-based CAI is the objective, specifically, the manner in which it is abstracted. We have pointed out that logical analysis may have little bearing on the learning process. The learning process is psychological. Many errors students make are not reducible to non-mastery of logical prerequisites, but are due to fundamental cognitive difficulties. What is the remedy in this case?

Clearly, cognitive difficulties encountered in learning would be minimized if psychological and not logical task analyses were the bases of lesson design. However, the preponderance of curricula are developed from a logical basis, e.g. without specific reference to how a corpus of knowledge forms a coherent and meaningful whole in the human learner. A fallback position, then, would be to use the

logical curriculum progressions and try to add as much branching as possible which is sensitive to the cognitive nature of some errors. This strategy quickly takes on an ad hoc or "add on" flavor, however. It attempts to address a fundamental problem in a roundabout way. Instead of treating the cognitive nature of knowledge integrally with its presentation in a systemic fashion, with this strategy, we treat only the symptoms. This fundamental discord created by reliance on the logical presentation of material to learners, sensitive to the much broader realm of psychological nuance, represents the single greatest limit to frame-based CAI and indeed, to all instruction.

Perhaps an example will help clarify what we mean by psychological difficulty. Suppose a student in an introductory electricity course has covered several basic phenomena, concepts, and results. His learning to this point is cumulative, his responses all indicate understanding. Now he is asked to solve a problem, and he is stumped. At this point, branching the student back to the logically prerequisite concepts and results will not help. He needs help not in the content he studies, but in problem solving technique. Help in this area will come from psychological understandings of problem solving behavior in the context of the electricity problem.

A second example will help further clarify the issue. A young girl has great difficulty with computation because, being highly intelligent, she relies to a great extent on her understanding as a guide to performance. The pat algorithms she is taught fail her. Logical analysis of the problem has traced and retraced all possible prerequisites to computation, including place value. She seems to have no difficulty with any prerequisite, yet her calculational

performance is poor. Suppose this girl's true difficulty was in understanding why we have a place value system. The logical treatment simply elaborated that we have one and how it works. But to her, this seemed arbitrary and therefore meaningless. The problem lies not in the realm of knowledge itself, but in how this girl treats knowledge, e. g. in her cognitive processes of understanding. She needed to know that the desire for a one-to-one correspondence between number and multi-digit numeral is the constraint at the root of the place value system.

As we stated above, insightful psychological task analyses are scarce. Such an approach to specific areas of learning is not well worked out. Indeed, much current work in cognitive psychology is directed at human processes of understanding and problem solving in complex realistic domains (Kintsch and Van Dijk, 1979; Larkin, et al., 1980). But these efforts are at the stage of developing theory. Cognitive psychologists are more interested in further advancement of theory than in applied educational work. At the same time, interested educators have only the tentative sketches provided by the cognitive theorists on which to base psychological task analyses. Because of this state of the art, a broad spectrum of schematic analyses or a compendium of useful results for use by the practitioner in the development of psychologically relevant analyses of curricula is no more than a wish list.

Local Difficulties: Before concluding, let us turn to the matter of branching within an objective. The same psychological/logical problem obtains; we can illustrate this problem as follows. If we use logic as the criterion to define an objective, then the boundaries

of the objective are defined logically. But these boundaries may not hold psychologically and the objective may take on an entirely different abstract shape which is not contained or encapsulated within the confines of the logical objective.

Gagne's treatment of instructional design for a logically derived objective is satisfactory at one level. He is careful to coordinate the sequence of instructional steps in the objective with certain conditions of learning derived from an information processing theory of cognition. Hence, for an objective, the instructional sequence seeks to develop a motivation to learn, to direct attention to salient features, to assist the learner's encoding processes into memory, and to elicit feedback for the learner by prompting some kind of performance. But Gagne's analysis of the conditions of learning is incomplete. The major omission is the recognition that not only the learner but knowledge too must be subjected to psychological analysis. Knowledge and learner come together at an intricate interface. At this interface, the learner and the knowledge, by definition of interface, are one in the same thing. It will not do, if quality instruction is a goal, to present knowledge as a fiat accompli. Neither will it do to reduce knowledge to logical square pegs (objectives) and try to pound them into psychological round holes (Gagneian conditions of learning). What is needed is a holistic attempt to discover the essence of and constituents of meaning in a body of knowledge and fit these with what is known about the acquisition of meaning by human learners.

In Conclusion: Some Practical Considerations

We predict that massive large-scale efforts to recast current

curricula in the frame-based CAI format will shortly ensue. SRA has recently announced the CMI portion of such a curricula for elementary mathematics. Computer Curriculum Corporation currently has drill and practice sequences for all of elementary mathematics. It is just a matter of time before detailed instruction is merged with these past efforts, all of which are based on logical task analyses. What will result from this massive conversion effort will largely replicate and perpetuate the instructional quality of our existing curricular materials. Contrary to McLuhan, the medium will change, but the message shall remain the same. It will be a grave mistake to view such conversions as fundamental advances in the practice of instruction.

But such conversions will provide opportunity for the beginnings of fundamental change. The psychological nature of instructional dialog will be much more central in the instructional design process, simply because of the interactive quality of the new medium. Learners will make errors and these need to be handled explicitly. Systems which ignore them or handle them by clumsy reference to other places in logical learning hierarchies will not be as attractive in the marketplace as systems which do a better job of response handling. This superior job of branching can be done by recognizing the psychological nature, not only of the learner, but also of knowledge.

Of course, the logical and psychological descriptions of knowledge are not completely divergent. In fact, where any given instructional lesson lies on the continuum between the two depends largely on the learner, specifically, on his or her characteristics

relative to the learning task at hand. Should a learner have to a great extent internalized the logical structure of a discipline, accretion of small amounts of additional knowledge would probably proceed well if the knowledge were presented logically. However, if a learner is just beginning to learn about a new area, a psychological approach would prove superior to a logical one. The relative ability to absorb logical arguments increases with age and mental sophistication. Hence, pilot training could be comfortable with logical curriculum analysis. But in the teaching of young children, or in the teaching of strange unfamiliar knowledge, a psychological approach would be recommended.

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